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Guide for the Application, Specification, and Testing of Phase-Shifting Transformers

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Contents

Guide for the Application, Specification, and Testing of Phase-Shifting Transformers

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International Standard IEC 62032/ IEEE Std C57.135-2011 has been processed through IEC technical committee 14: Power transformers, under the IEC/IEEE Dual Logo Agreement.

This second edition cancels and replaces the first edition, published in 2005, and constitutes a technical revision.

The text of this standard is based on the following documents:

IEEE Std	FDIS	Report on voting
IEEE Std C57.135-2011	14/710/FDIS	14/714/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

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- withdrawn,
- replaced by a revised edition, or
- amended.

IEEE Std C57.135™-2011
(Revision of
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IEEE Guide for the Application, Specification, and Testing of Phase-Shifting Transformers

Sponsor

Transformers Committee
of the
IEEE Power & Energy Society

Approved 16 June 2011

IEEE-SA Standards Board

Abstract: Theory, application of phase-shifting transformers, and the difference of specification and testing to standard system transformers are described in this guide. Various types of phase-shifting transformers and how to select the optimal design to achieve required control of power flow are covered. An understanding of the terminology, types, construction, and testing specific to phase-shifting transformers is provided.

Keywords: advance phase angle, dual-core design, IEEE C57.135, main transformer, phase-shifting transformer, power transfer, retard phase angle, series transformer, single-core design, special tests

IEEE Introduction

This introduction is not part of IEEE Std C57.135-2011, IEEE Guide for the Application, Specification, and Testing of Phase-Shifting Transformers.

This guide describes the application, specification, and testing of phase-shifting transformers. It is intended for the following:

— Organizations responsible for the application and specification of phase-shifting transformers for electric transmission systems to control power flow.

— Organizations responsible for testing phase-shifting transformers.

This guide is designed to help organizations:

— Understand the various types of phase-shifting transformers and how to apply them to obtain required control of power flow.

— Prepare specifications for the purchase of phase-shifting transformers.

— Standardize tests and test methods for phase-shifting transformers.

This guide is intended to satisfy the following objectives:

— Promote consistency within organizations for the application and specification of phase-shifting transformers.

— Provide an understanding of the terminology, types, construction, and testing relating specifically to phase-shifting transformers.

— Promote the standardization of testing procedures for phase-shifting transformers.

Since this guide was first published in 2001, several recommendations from users and manufacturers were made to revise it to improve accuracy and applicability. Some of the revisions are as follows:

— Figure 1, Figure 3, Figure 4, Figure 7, and Figure 11 were improved.

— Equation (1) was divided into two parts to show the difference between advance and retard operations.

— A new section on minimum information requirements for specifying a PST was inserted.

— Various editorial changes were made to clarify the contents of the guide.

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Guide for the Application, Specification, and Testing of Phase-Shifting Transformers

1. Overview

1.1 Scope

This guide covers the application, specification, theory of operation, and factory and field testing of single-phase and three-phase oil-immersed, phase-shifting transformers (PSTs).

This guide is limited to matters particular to PSTs and does not include matters relating to general requirements for power transformers covered in existing standards, recommended practices, or guides.

1.2 Purpose

The terminology, function, application, theory of operation and protection, and design of PSTs are not covered by existing transformer standards and guides. The purpose of this document is to provide guidance to those specifying, designing, and using PSTs.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEC 60076-1, Power Transformers—Part 1: General.[1]

IEC 60076-3, Power Transformers—Part 3: Insulation Levels, Dielectric Tests and External Clearances in Air.

IEC 60076-5, Power Transformers—Part 5: Ability to Withstand Short Circuit.

IEC 60076-7, Power Transformers—Part 7: Loading Guide for Oil-Immersed Power Transformers.

IEEE Std 693™, IEEE Recommended Practice for Seismic Design for Substations.[2,3]

IEEE Std C37.90.1™-1989, IEEE Standard for Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus.

IEEE Std C57.12.00™, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.12.80™, IEEE Standard Terminology for Power and Distribution Transformers.

IEEE Std C57.12.90™, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers, and IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers.

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary: Glossary of Terms & Definitions*[4] should be consulted for terms not defined in this clause.

All other definitions, except as specifically covered in this guide, shall be in accordance with IEEE Std C57.12.80™.[5]

advance phase angle: The phase angle expressed in degrees that results when the load (L) terminal voltage leads the source (S) terminal voltage.

excitation-regulating winding: A two-core phase-shifting transformer (PST) design in which the exciting unit has one winding operating as an autotransformer that performs both functions listed under excitation and regulating winding of a two-core PST.

[1] IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3 rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.
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[4] The *IEEE Standards Dictionary: Glossary of Terms and Definitions* is available at http://shop.ieee.org.
[5] Information on references can be found in Clause 2.

excitation winding: The winding of a phase-shifting transformer (PST) that draws power from the source to energize the PST.

excited winding of a two-core phase-shifting transformer (PST): The winding of the series unit that is excited from the regulating winding of the exciting unit.

exciting unit of a two-core phase-shifting transformer (PST): The core and coils that furnish excitation to the series unit.

L terminal: The L terminal is the terminal that is used to measure the voltage phase-shift angle when compared to the S terminal of the phase-shifting transformer (PST).

primary winding of the exciting unit of a two-core phase-shifting transformer (PST): The winding on the high-voltage side of the exciting unit.

phase-shifting transformer (PST): A transformer that advances or retards the voltage phase-angle relationship of one circuit with respect to another.

rated kVA of a phase-shifting transformer (PST): The apparent power at rated voltage for which the PST is designed.

rated phase angle of a phase-shifting transformer (PST): The phase angle measured between the S and L terminals at maximum advance and/or retard tap position under no-load condition.

rated voltage of a phase-shifting transformer (PST): The phase-to-phase voltage to which operating and performance characteristics are referred. The voltage ratings are to be defined at no-load and based on turn ratios.

regulated circuit of a phase-shifting transformer (PST): The circuit on the output side of the PST in which it is desired to control the voltage, the phase relation, or both.

NOTE—In the regulated circuit the voltage may be held constant, or may vary with or without relation to the phase angle depending on the type of PST.[6]

regulating winding: The winding of a single-core phase-shifting transformer (PST) or of the exciting unit of a two-core PST in which taps are changed to vary the phase angle.

retard phase angle: The phase angle expressed in degrees that results when the L terminal voltage lags the S terminal voltage.

series unit of a two-core phase-shifting transformer (PST): The core and coil unit that has one or more windings connected in series with the line circuit.

series winding(s) of a two-core phase-shifting transformer (PST): The winding(s) of the series unit that is(are) connected in series in the line circuit.

single-core design: A single-core phase-shifting transformer (PST) has all windings mounted on a single core.

S terminal: The S terminal is the terminal that is used as the fixed reference point when measuring the voltage phase angle of a phase-shifting transformer (PST).

[6] Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

two-core design: A two-core phase-shifting transformer (PST) consists of a series unit and a exciting unit. The series and the exciting unit can be either in one tank or in separate tanks.

4. Application and theory of PSTs

4.1 Introduction

The development of large, high-voltage power grids has enabled power consumers to enjoy the benefits of more reliable and efficient service and has allowed generation sources to be, in some cases, located long distances from large load centers. Although large interconnected grids strengthen a power system's reliability, complications can arise with the control of steady-state power flow along certain segments of the system. These complications can be attributed to several factors, including the impedance of parallel paths in the power grid, variation in power generation output, and variation in loads and load center phase angles.

4.2 Basic principle of application—advanced and retard phase angle

PSTs are used to control the power flow in electrical power systems. When power flows between two systems, there is a voltage drop and a phase-angle shift between the source and the load that depends upon the magnitude and power factor of the load current. If the systems are connected together in two or more parallel paths so that a loop exists, any difference in the impedances will cause unbalanced line loading. Figure 1 shows an example with the load side power factor assumed to be 1 and the system resistances being negligible with respect to their reactances. An arbitrary power flow distribution can be obtained by inserting a PST into one of the branches. Dependent upon whether the PST is installed in the branch with the higher or lower impedance, an advanced or a retard phase angle is needed. *Advanced* means that the L terminal voltage (V_L) leads the S terminal voltage (V_S); *retard* means that the L terminal voltage (V_L) lags the S terminal voltage (V_S).

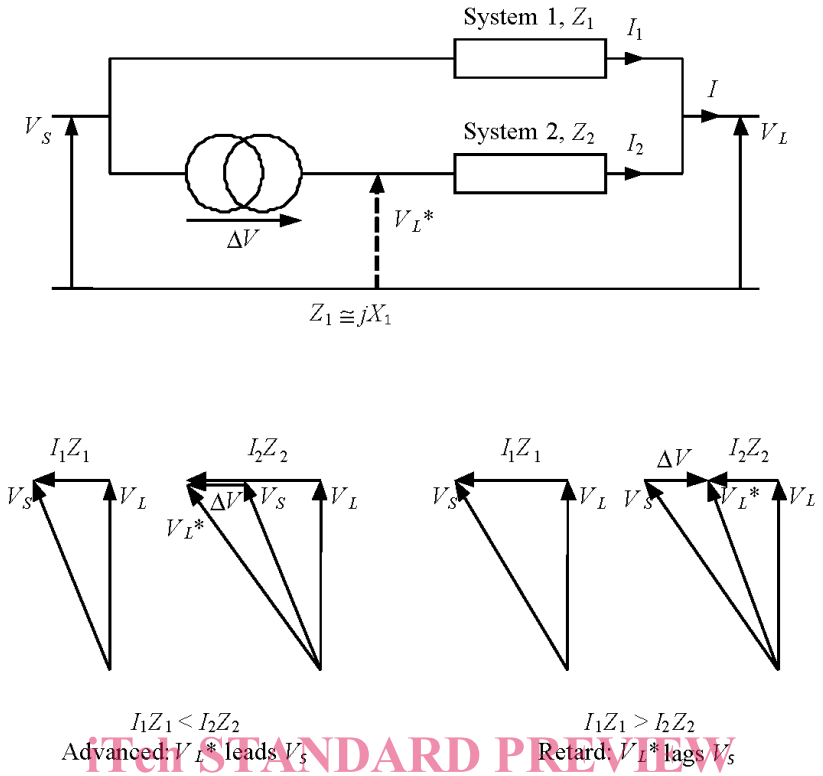

Figure 1—Load side power factor of 1

Equation (1a) and Equation (1b) illustrate the advance and retard operations shown in Figure 1.

$$I_2 * Z_2 - \Delta V - I_1 * Z_1 = 0 \quad \Rightarrow \quad \Delta V = I_2 * Z_2 - I_1 * Z_1 \tag{1a}$$

$$I_1 * Z_1 + \Delta V - I_2 * Z_2 = 0 \quad \Rightarrow \quad \Delta V = I_2 * Z_2 - I_1 * Z_1 \tag{1b}$$

A numerical example should illustrate this. If it is required that both systems are loaded with 50% of the total transferred power 2xS and the impedances are assumed to be $z_1 = 0.02$ and $z_2 = 0.30$, related to S, the necessary additional voltage becomes $\Delta V = 0.30 - 0.02 = 0.28$. Hence, a load phase angle (advanced) of about 15.6° (≈arctan(0.28)) is necessary. The total angle between source and load becomes minus 1.1°. In case with $z_1 = 0.30$ and $z_2 = 0.02$, the same load phase angle (retard) would be needed, but the total phase angle between source and load would become 16.7°. If no measures were taken, then the load distribution between system 1 and 2 would be 0.9375 to 0.0625 instead of 0.5 to 0.5.

A second important application is the use of a PST to control the power flow between two large independent grids. An advanced phase-shifting angle is necessary to achieve a flow of active power from system 1 to system 2 (Figure 2).